Reprinted from JOURNAL OF APPLIED METEOROLOGY, Vol. 16, No. 12, December 1977
American Meteorological Society
Printed in U. S. A.

Microclimate as Background Environment for Ecological Studies of Insects in a Tropical Forest

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ABSTRACT

Microclimate data collection and analyses were made in support of an ecological study of changes in transmission cycles of insect-borne disease during a three-year period of construction of a hydroelectric dam. The dam will cause impoundment of some 300 km^2 of tropical forest in the Bayano River Basin, Panama. The pre-impoundment microclimate appeared to be one of strong seasonality with appreciable changes in the wind flow, sensible and latent heat flux, evaporation, rainfall and humidity. Average daily net radiation balance was 106 W m^{-2} above the forest canopy and 46 W m^{-2} on the floor of the forest. The moisture balance of the forest indicates an annual rainfall of 2 m of which 1 m reaches the floor of the forest. An appreciable amount of rain is intercepted in the forest canopy. The evaporation and runoff on the forest floor are both about 0.5 m. Average daily wind speeds are light, varying from 8 km day^{-1} in the rainy season to 126 km day^{-1} in the dry season. Ecological significance was found in the nocturnal unstable vertical temperature profile of the forest and the associated small updrafts and downdrafts which may permit easier vertical migration of forest insects at night. Rainfall and light wind speeds during 24 h periods of collection seem to appreciably affect the activity of the most abundant man-biting species of insects.

1. Introduction

The challenge of the present energy crisis is causing many Latin American countries, such as Colombia, Salvador, Surinam and Panama, which lack natural petroleum reserves, to shift from fossil fuels to hydroelectric power as a source of energy. In Panama alone there is one such hydroelectric dam and reservoir which began impoundment of the Bayano River in February 1976, and there are four additional hydroelectric projects that have reached the late planning stages. It is certain that many more man-made lakes will shortly be formed in the American tropics, and these may bring about microclimatic and ecological changes.

When the construction of Panama's first hydroelectric dam was initiated, the Gorgas Memorial Laboratory undertook a project to study and record the changes of the microclimate and disease transmission cycles in a tropical forest, resulting from such construction and the flooding of forested lands. Changes that occurred during the periods of preflooding, impoundment and post-impoundment would then be correlated with those pertaining to the natural history of infectious diseases that are primarily insect borne. Conceived as an interdisciplinary effort, it was the first long-term study of microclimate within a tropical forest which permitted close examination of the relationship between the physical environment and the ecology of insect-borne disease. The concept discussed here is that while the formation of a large man-made lake in the tropical forest may dramatically change the natural transmission cycles of insect-borne disease in the area, subtle and less noticeable changes in the microclimate may be a major factor in controlling the population dynamics of insect carriers of disease.

The dam is located on the Bayano River about 70 km east of the Pacific entrance to the Panama Canal. The impoundment is about 300 km^2 and extends some 60 km east of the dam (Fig. 1). Within this area, two high points are becoming "islands." In the spring of 1972, the Gorgas Memorial Laboratory chose the largest of these two islands, Los Altos de Majé, to house the main camp, laboratory and field site as a base from which to study the ecology of insect-borne forest diseases such as malaria, jungle yellow fever and Venezuelan equine encephalitis. In September 1972 it was decided to investigate the forest microclimate where the insect collections and other studies were being accomplished. The physical environmental factors would then provide background data for any biological study during the base line period of preimpoundment. The microclimate of 1973–75 in that forest location will be discussed.

The term microclimate is applicable strictly to the atmosphere of a restricted space, more or less rigorously enclosed and completely sheltered from the factors of local climate (Sorre, 1961). Forest meteorology or climatology is a special case of the climatology of en-

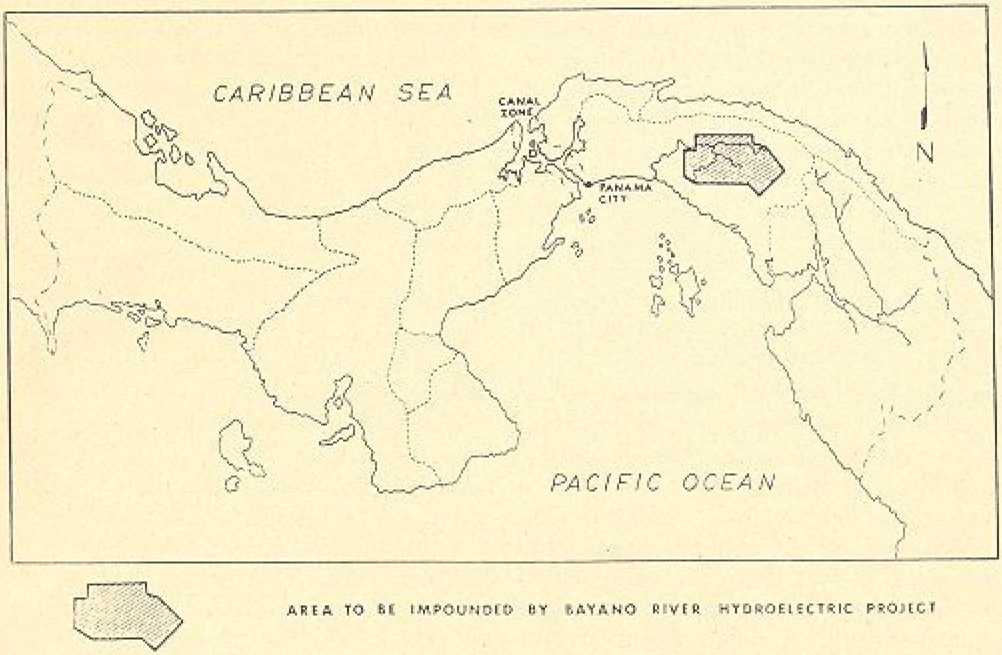

Fig. 1. Map of Panama and the area to be impounded in the Bayano River basin.

closed space. It is midway between the climatology of open space, and that of a building or a room, within which movement of the outside atmosphere is eliminated almost entirely and the meteorological variables are modified considerably.

The forest area affected by construction of the Bayano River dam is so large that any complete study is impossible. Each forest must be considered as a specific plant community, defined in terms of its composition, functions, structure and dynamics. Fortunately, the forest cover around the periphery of the Bayano impoundment is relatively homogeneous and, as a result, the changes in microclimate and the corresponding ecological changes may be adequately interpreted by measurements made at the field site of Los Altos de Maje. During the baseline period (1973–75) of preflooding, the main microclimate station was ideally located on the heights near the river on the floor of the valley and provided representative estimates of the preflooding microclimate in the river basin. For the period of flooding, the island location is well situated to measure changes produced by the impoundment. The post-flooding island microclimate will be representative of a strip of land surrounding the lake and thus the area most exploited by man.

In 1972 and 1973, the Bayano River basin east of the dam site was composed of uncut forest. At that time, the main camp and helicopter pad appeared by aerial view as a very small clearing in many miles of uncut forest land. During the dry season, January–April 1974, the forest in the river valley was clear-cut up to the elevation where the flood waters were expected to rise. This left approximately 5000 acres of Los Altos de Maje as the only untouched forest land is that part of the river valley. Where the original climax forest had been cut and burned, there was rapid growth, during 1974 and 1975, of a secondary forest of large-leafed and soft wood trees.

2. Methods and procedures

In the fall of 1972, the principal microclimate station was established on a hog-back ridge with forested slopes. From the elevation and location, measurements were representative of those at the top of the forest canopy and, hence, of the free air flow in the Bayano River basin. Daily measurements were made of the rainfall, evaporation, wind and maximum and minimum temperatures. Continuous measurement was made of the temperature and relative humidity, solar radiation and rainfall intensity. A secondary microclimate station was established about 500 m in the forest from the main camp. There, a wooden tower was erected extending 21 m into the canopy. Daily measurements were made of forest rain drip, evaporation from the forest floor, and maximum and minimum temperatures at five different levels on the tower. From the comparison of the measurements taken at those stations, the moisture and radiation budgets of the forest were computed. Other observations were made in the forest in support of the biological research in progress. These included hourly measurements of wet and dry bulb temperatures at two tower locations, one at 1 m above the ground and the other within the canopy, at a height of ~20 m. Wind measurements were taken daily, and hourly when necessary. A simple totalizing contact anemometer, which did not require the use of electric power, was used to measure wind speeds.

The anemometer was typical of the unsophisticated but practical instruments which were utilized, since the tropical forest environment is extremely hostile to complex instrumentation. At two-week intervals, all instruments were returned to the laboratory for cleaning, repair and calibration. For example, anemometers were changed to prevent errors in measurement, which might arise as bacteriological growth collected on the drive shafts. With the light winds experienced in the region, it was found that an anemometer left in the field for a month would only measure about 50% of the daily air flow.

Other instruments, not routinely available, were fabricated and calibrated in the laboratory prior to being placed in the field. To accurately measure forest rain drip, a term defined as the measure of through fall of rain from the forest canopy, while it is raining, plus the dripping which reaches the ground during the period of measurement, it was necessary to design a collector with a surface sufficiently large to provide representative measurements. A raingage was manufactured from heavy sheet metal, 10 m long and 10 cm wide, which was then located in a forest area representative of the canopy in general. Each liter of water collected indicated 1 ml of through fall or forest rain drip. Fig. 2 is an illustration of the forest rain drip gage at Los Altos de Maje.

It is difficult to measure evaporation under the best of conditions, but especially so in tropical regions of heavy rainfall. Black and white porcelain spherical evaporimeters were used to measure the potential evaporation. The spherical shape of these instruments approximated the natural evaporating surfaces and best suited the needs of practicability in measuring evaporation in a tropical forest (Read, 1968). The ratio of average potential evaporation to the average precipitation, the potential evaporation ratio (E/P), is used as an index of biological humidity conditions. A ratio of 1.00 indicates precipitation is equal to evaporation.

When the ratio is greater than 1 this indicates the water needs of the forest are not being met by the precipitation alone, and must be supplemented by the water in the vegetation and that which is stored in the soil during the rainy season. This is manifested in the changing color of the vegetation from a green to a yellowish brown, and by the cracking of the forest floor during the dry season.

The average amount of evaporation from the two evaporimeters was used to compute the mean net radiation. The black evaporimeter tended to maximize and the white evaporimeter to minimize the amount of radiation absorbed in the process of evaporation. The absorption of the natural evaporating surface was taken to be the average of the two instrument surfaces. In the tropical forest the main method by which radiative surpluses of the vegetative surfaces are dissipated and transferred vertically to the atmosphere is by evaporation of water. Budyko (1956) and Sellers (1965) state that the potential evaporation from a fully wet surface is very closely related to the radiation budget of the wet surface. In fact, if all available radiative energy is used for evaporation and there are no other energy sources, the radiation budget is equal to the flux of latent heat. The assumption is made here that the radiation budget of the wet surface is a good approximation to that of the natural evapotranspiring surfaces in the tropical forest.

The radiation budget at the surface of the earth in

FIG. 2. Forest rain drip collector on the forest floor at Los Altos de Maje.

a tropical forest may be written

$$R=Q_s+Q_e+S,$$

where R is the net amount of radiation absorbed at the surface, Q_s the energy given off as sensible heat, Q_e the energy given off as latent heat, and S the storage of heat which may be neglected in the annual heat balance because heat stored in the morning and early afternoon is almost balanced by heat loss in the late afternoon and night (Sellers, 1965). The amount of radiation stored temporarily in a forest on a summer day is very small, about 1%. During the course of a day there is nearly a complete turnover in the energy budget (Reifsnyder and Lull, 1965). On this basis the radiation budget becomes

$$R=Q_s+Q_e.$$

In the oceans equatorward of the subtropical ridge Q_s is about 0.1 Q_e (Simpson, 1970) and near the equator Q_s is about 0.05 Q_e (Sellers, 1965). In this tropical forest of Panama, which is at about 9°N latitude, and never more than 50 mi from the ocean, a reasonable value for Q_s is 0.1 Q_e.

Substituting LE for the flux of latent heat, where L is the latent heat of vaporization and E the potential evaporation, and using the ratio $Q_s/Q_e=0.1$, the radiation budget becomes

$$R=1.1LE.$$

Computations of the net radiation were made from the potential evaporation at the main climate station and on the floor of the forest at the tower location. It should be noted that the computations are order-of-magnitude solutions. Errors in measurement may occur during periods of heavy rainfall when, for example, on the forest floor no measurable evaporation takes place for several days and, below the forest canopy, the air is very stagnant and humid.

3. Results

The net radiation balance is shown in Fig. 3. The average daily net radiation varies throughout the year, with higher values in the dry season than in the rainy season. There are also appreciable variations between the daily averages and the maximum values during the month. The average daily net radiation at the canopy level for both years was about 106 $\mathrm{Wm^{-2}}$ and on the floor of the forest 46 $\mathrm{Wm^{-2}}$. The average daily total insolation (I) and radiation balance (R) for the period August 1974–May 1975 are shown in Fig. 4 and refer to measurements made at the main camp. The period December–April was dry season with monthly rainfall less than 10 cm. The ratio $R/I\times 100$ during this period was about 38%, while in the rainy season, it was 23%. These data give an approximation of the percentage of incoming solar radiation used primarily for evaporation during the wet and dry seasons.

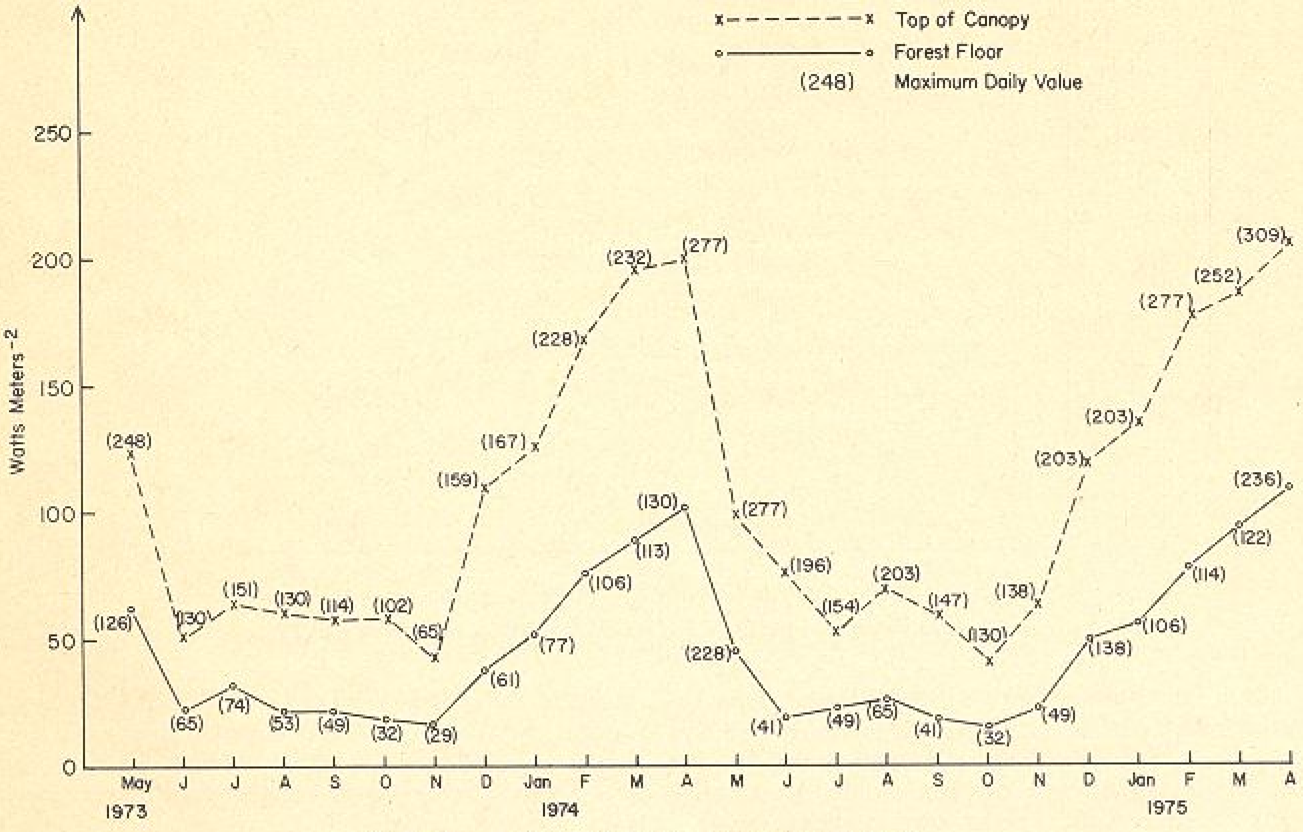

Fig. 3. Average daily net radiation at Los Altos de Maje.

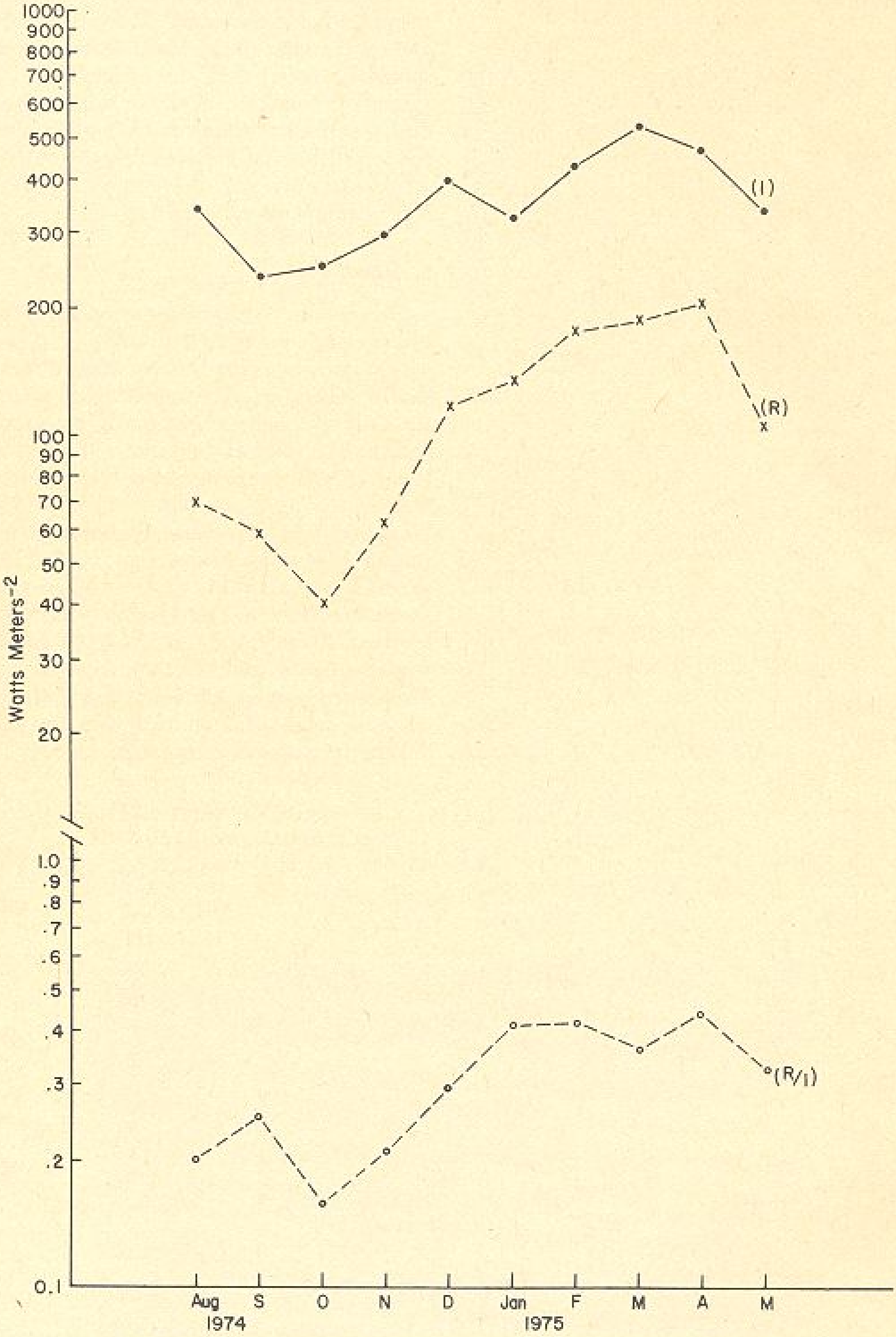

FIG. 4. Incoming solar radiation and net radiation, August 1974–May 1975.

Rain was measured with a standard gage above the canopy at the main camp site, and the forest rain drip was measured at the forest microclimate station. The canopy intercept was taken as the difference between daily measurements at the two locations. Table 1 shows the moisture data at the Bayano River basin location. When light rainfall occurs, the rain accumulates in the canopy and does not reach the ground. For example, in 1973 on 5, 6, 10, 16, 18 and 26 July, there was 1 mm of rain measured at the main camp and no rain drip was measured at the ground in the forest. The canopy intercept for those days was 1 mm day^{-1}.

There was also considerable variation in the amount of rain drip that reached the ground. On 15 July 1973 there were 43 mm of rain measured above the canopy and 10 mm measured on the forest floor, while nine days later on 24 July there were 46 mm of rain measured above the canopy and 36 mm measured on the forest floor. In both years there were more days with rain within the forest canopy than there were on the ground. Thus, in 1974–75 there were 158 rainy days within the forest canopy and only 112 days with throughfall to the floor of the forest. Of the approximate 202 cm of rainfall, 97 cm remained in the forest canopy and evaporated into the atmosphere.

On an annual basis, the potential evaporation ratio E/P was about 60% at the main camp and about 45% on the floor of the forest. The data show that there are four to five months during the year when the ratio indicates very dry periods and seven to eight months of very wet periods. On an annual basis, the ratio indicates an excess in the water needs of the forest.

Wind speeds were light in this forested location and standard measurements in kilometers per hour or meters per second were not practicable. A more meaningful measure was the daily air movement or ventilation in units of *kilometers per day*. Maximum wind gusts were on the order of 13–16 km h^{-1}. Wind directions were primarily from the north ±45°, except just preceding and during periods of heavy rainfall, when they most often shifted to a southerly direction. Table 2 shows the wind and rainfall during the two periods of record.

There was normally little horizontal air flow during periods of darkness. During the period discussed here, heavy fog or low clouds formed at night in the lower elevations of the river valley. Below the main climate station on the ridge, there was a heavy overcast which completely obscured the valley. This fog usually started to form between 2200 and midnight, as the downslope drainage of air settled to the valley floor. In 1973, this overcast persisted until about 0830. After

TABLE 1. Moisture budget, Los Altos de Maje, 1973–75.

	Top of canopy				Forest floor				Canopy intercept	
Date	Evaporation E (cm)	Rain P (cm)	E/P	Days rain	Evaporation E (cm)	Rain P (cm)	E/P	Days rain	Rain R (cm)	Days rain
1973										
May	12.07	15.9	0.76	18	6.01	11.0	0.55	10	4.9	17
Jun	4.86	29.2	0.17	26	2.18	16.2	0.13	19	13.0	25
Jul	6.34	19.8	0.32	21	3.15	9.9	0.32	13	9.0	20
Aug	5.97	28.5	0.21	22	2.02	12.8	0.16	15	15.7	20
Sep	5.5	24.2	0.23	23	2.09	13.0	0.16	14	11.2	21
Oct	5.73	37.6	0.15	29	1.78	27.4	0.06	23	10.2	28
Nov	4.0	39.5	0.10	25	1.5	24	0.06	23	15.5	22
Dec	10.76	6.4	0.59	13	3.48	3.7	0.94	6	2.7	10
1974										
Jan	12.21	0.3	40.7	2	4.84	0	—	0	0.3	2
Feb	14.85	0	—	0	6.53	0	—	0	0	0
Mar	18.98	0.1	189.8	1	8.45	0	—	0	0.1	1
Apr	18.77	1.6	11.73	6	9.45	0.7	13.5	1	0.9	5
Total	120	203.1		186	51	118.7		124	84	171
1974										
May	9.63	28.1	0.34	17	4.42	12.4	0.36	11	15.7	17
Jun	7.18	30	0.24	22	1.77	15.6	0.11	13	14.4	19
Jul	5.17	22.1	0.23	20	2.16	13.5	0.16	14	8.6	18
Aug	6.74	29.5	0.23	21	2.47	14.4	0.17	13	15.1	21
Sep	5.49	19.1	0.29	23	1.73	7.1	0.24	18	12.0	22
Oct	3.89	41.5	0.09	31	1.50	27.1	0.06	23	14.4	31
Nov	5.91	23.6	0.25	24	2.09	11.8	0.18	18	11.8	22
Dec	11.55	6.9	1.67	5	4.84	2.8	1.73	2	4.1	5
1975										
Jan	12.87	0	—	0	5.45	0	—	0	0	0
Feb	15.41	0	—	0	6.78	0	—	0	0	0
Mar	18.08	0	—	0	8.66	0	—	0	0	0
Apr	19.19	0.8	23.99	3	10.08	0	—	0	0.08	3
Total	121	201.6		166	52	104.7		112	96	158

TABLE 2. Rainfall and wind data at Los Altos de Maje. Units: rain (mm), wind (km day^{-1}).

Date	Rain	Average daily wind	Daily maximum wind	Date	Rain	Average daily wind	Daily maximum wind
1973				1974			
May	159	42	101	May	281	56	105
*June	292	5	18	*Jun	300	50	93
*Jul	198	11	32	*Jul	221	45	92
*Aug	285	8	23	*Aug	295	37	81
*Sep	242	13	31	*Sep	191	34	116
*Oct	376	14	32	*Oct	415	34	60
*Nov	395	19	34	*Nov	236	44	127
*Dec	64	43	85	*Dec	69	52	85
1974				1975			
Jan	3	58	98	Jan	0	68	85
Feb	0	83	135	Feb	0	81	114
Mar	1	80	132	Mar	0	105	143
Apr	16	126	187	Apr	8	109	153

* Rainy season months; May and December are transition months between the rainy and dry seasons.

sunrise at about 0600, the air temperatures remained cool and no measureable wind was observed until the cloud had almost evaporated. At that time, the anemometer began to turn slowly and air temperatures started to rise. This radiation or drainage fog occurred in both the rainy and dry season. During this period, the fog never reached the camp site and the overcast was at least 30 m below the ridge. After the forest cutting in 1974 and 1975, the level of the overcast rose to include the camp site and often did not evaporate until much later in the morning.

As an adjunct to entomological studies, biweekly observations of wet and dry bulb temperatures were made throughout a 24 h period at the 1 m level and in the middle of the canopy at the 20 m level. Tables 3 and 4 show the results of these measurements for the year 1973, when little forest cutting had taken place in the vicinity of Los Altos de Maje. These tables indicate both the nighttime (1800–0500) and daytime (0600–1700) temperature and humidity conditions. The range of temperatures near the floor of the forest during the nighttime was 22–31°C and the daytime range 22–37°C. The forest is semi-deciduous and near the end of the dry season in April, appreciable sunlight may penetrate to the forest floor. In the canopy, the nighttime range of temperatures was 22–30°C and the daytime range 22–37°C. The daytime vapor pressures were consistently greater than during the night at both the ground and within the canopy. There was little vertical gradient of vapor pressure during the night, but daytime vertical gradients were present and could be increasing upward or downward at different months of the year.

4. Discussion

The function of a forest is to provide shade and it is the tree canopy which creates a microclimate. The canopy intercepts rain showers, reduces the amount of solar radiation reaching the ground, and thereby lowers the air temperature and increases relative humidity. It reduces the wind, permits accumulation of stagnant moist air and diminishes the rate of evaporation near the ground.

The average net radiation at the floor of the forest was about 43% of that at the top of the canopy for both years. These data show that much less energy is available on the floor of the forest for evapotranspiration, and the warming of the air, plants and animals. They may explain why certain insects prefer the environment near the floor of the forest, while others adapt to the canopy of the forest. In April 1974, during the dry season, the average daily net radiation was high, but on one day during the month, the amount of energy was about 30% greater than average. This may affect the activities of animal life in the forest. It is a common observation in a tropical forest that on certain days, everything seems to be moving while on other days, little animal life is observed. The living organism is not subject to a mean climatic state. On the contrary, it integrates various effects due to a more

TABLE 3. Temperature and humidity at the 1 m level in the forest of Los Altos de Maje for nighttime and daytime periods.

1973	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1800–0500												
Temperature (°C) range	23–28	24–27	26–31	23–31	23–29	23–27	22–27	23–26	23–28	22–30	22–25	23–30
mean	26	26	27	26	26	25	25	24	26	24	24	24
Mean dew point	24	23	24	23	24	23	24	23	23	23	23	23
Vapor pressure (mb) range	29.46–32.51	27.09–29.80	28.11–31.83	23.70–32.17	27.43–53.19	26.41–30.82	25.40–34.54	27.09–34.20	23.03–31.49	26.75–32.85	25.40–31.83	24.04–29.12
mean	29.80	28.11	29.80	27.77	29.80	28.45	29.12	29.12	28.78	28.45	28.78	27.77
0600–1700												
Temperature (°C) range	23–30	24–28	24–31	22–37	24–35	22–31	22–31	22–32	22–31	22–27	23–27	23–30
mean	27	27	29	31	27	27	27	27	26	25	25	26
Mean dew point	25	23	24	24	25	25	25	24	24	24	24	22
Vapor pressure (mb) range	26.41–37.25	26.75–30.14	29.12–32.17	24.38–32.51	26.41–38.60	25.40–40.30	25.40–39.96	19.98–37.25	24.38–33.86	22.35–35.56	27.43–32.85	21.00–30.14
mean	32.17	28.45	30.48	29.12	31.15	31.83	32.17	29.46	30.14	30.82	29.46	27.09

TABLE 4. Temperature and humidity within the canopy at 21 m level in the forest of Los Altos de Maje for nighttime and daytime periods.

1973	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1800–0500												
Temperature (°C)												
range	23–28	23–26	26–30	23–30	23–29	23–26	22–27	22–26	23–27	22–28	22–26	23–26
mean	26	25	27	26	26	24	24	24	25	23	24	24
Mean dew point	24	22	22	23	24	23	24	23	23	23	23	23
Vapor pressure (mb) range	27.43–32.51	24.04–28.45	27.09–32.51	26.08–30.48	26.41–32.51	26.08–29.80	24.72–34.54	26.08–30.14	27.09–30.14	24.38–33.86	25.40–31.15	26.08–29.12
mean	29.80	27.09	27.09	28.11	29.46	28.11	29.46	28.45	28.45	27.77	28.11	27.77
0600–1700												
Temperature (°C)												
range	23–30	23–32	24–32	23–37	23–36	22–32	22–32	23–32	22–32	23–30	23–27	23–30
mean	27	27	29	30	28	27	28	27	26	26	25	26
Mean dew point	25	23	24	24	25	25	26	24	24	24	23	22
Vapor pressure (mb) range	26.41–36.57	24.04–32.51	28.11–31.83	24.04–40.64	23.03–38.60	24.04–37.59	25.40–45.04	24.04–35.90	24.04–33.86	27.43–33.86	25.40–32.51	22.01–29.46
mean	32.17	27.77	30.14	30.82	31.15	31.49	32.85	30.48	29.12	29.80	28.78	26.75

or less wide range of short-term combinations of different climatic factors. For example, in developing a model of the hygrothermal space occupied by insects during man-biting activity in the forest the hourly values of temperature and vapor pressure were used. The use of monthly or daily means of climatic elements in bioclimate indices can lead to results that may not be representative.

The moisture balance of rainfall, evaporation and runoff is shown in Fig. 5. Throughfall of rain reaching the forest floor is primarily due to rain drip from the canopy. In most cases, the quantity of stem flow is quite small in relation to throughfall and may be ignored (Wadsworth, 1967). The rainfall at the top of the canopy should equal the sum of the potential evaporation and the throughfall to the forest floor, assuming there is little storage over a period of a year and the rainfall intercepted by the canopy has all evaporated. In both years the sum of the two terms exceeds the incoming rainfall by 10–15%. This implies that the potential evaporation may be in excess of the actual forest evapotranspiration, or that there is an error in measurement of the throughfall at the forest floor. The two measurements may combine to produce the error. Since the problem of obtaining a truly accurate measure of throughfall in the forest is very difficult to solve, the error most probably is largely found in the measurement of throughfall. Essentially, for the two years recorded, there were 2 m of rainfall. About 1 m was throughfall to the floor of the forest and approximately 0.5 m evaporated from the forest floor; thus the runoff was about 0.5 m.

Since about 50% of the available rainfall reaches the forest floor, it is of interest to consider the erosive effects of rainfall in the tropics. The effect may be substantial since about 20% of the rain comes in the form of cloudbursts, which have the capacity to release 1.0 mm of rain per minute for periods of 5 min or more. The erosive effects of water increase exponentially with increase in flow, so that if the flow is doubled, the scouring capacity quadruples, the carrying capacity increases 32 times and the size of particles transported increases 64 times (Meggers, 1971).

Since the microclimate data collection and analyses were made to support the ecological study, it was necessary to determine what climate elements such as wind, rain, humidity, evaporation and temperature are useful as the physical environmental background. Gates (1962) argues that ecologists have been guilty of measuring certain climatological factors as interesting features of the environment, without relating these parameters to physical processes affecting an organism in question. Wind measurements may fall under such a classification. The moving air is the vehicle for turbulent transfer of momentum, heat, water vapor and chemicals. In the forest, humidity is a function of the interaction between temperature, precipitation, and soil and plant cover, yet the flux of moisture to the air from evaporating surfaces depends largely on turbulent motion of air. Although there is, in general, little ventilation in the tropical forests of Panama when the wind flow above the forest is relatively strong and gusty, the forest canopy is an active exchange zone, bringing outside drier air through the canopy and exhausting the moist air from near the forest floor (Read, 1968).

It is difficult to separate variables of the climate and relate them to organisms under study. One example will suffice to show the importance of the physical elements to the collection of an insect species. The most abundant man-biting species of insects collected during the two periods of record, using man as live bait, was *Culicoides diabolicus*. These are miniscule sand fly pests, called "no-seeums." During the period May to December 1973, on days during which 24 h collections were made—295 273 *Culicoides diabolicus* were collected. About 99% were collected on days when it rained and the winds were less than 31 km day^{-1}. In 1974 during the same period, 23 174 of these insects were caught, and again all were collected on days with

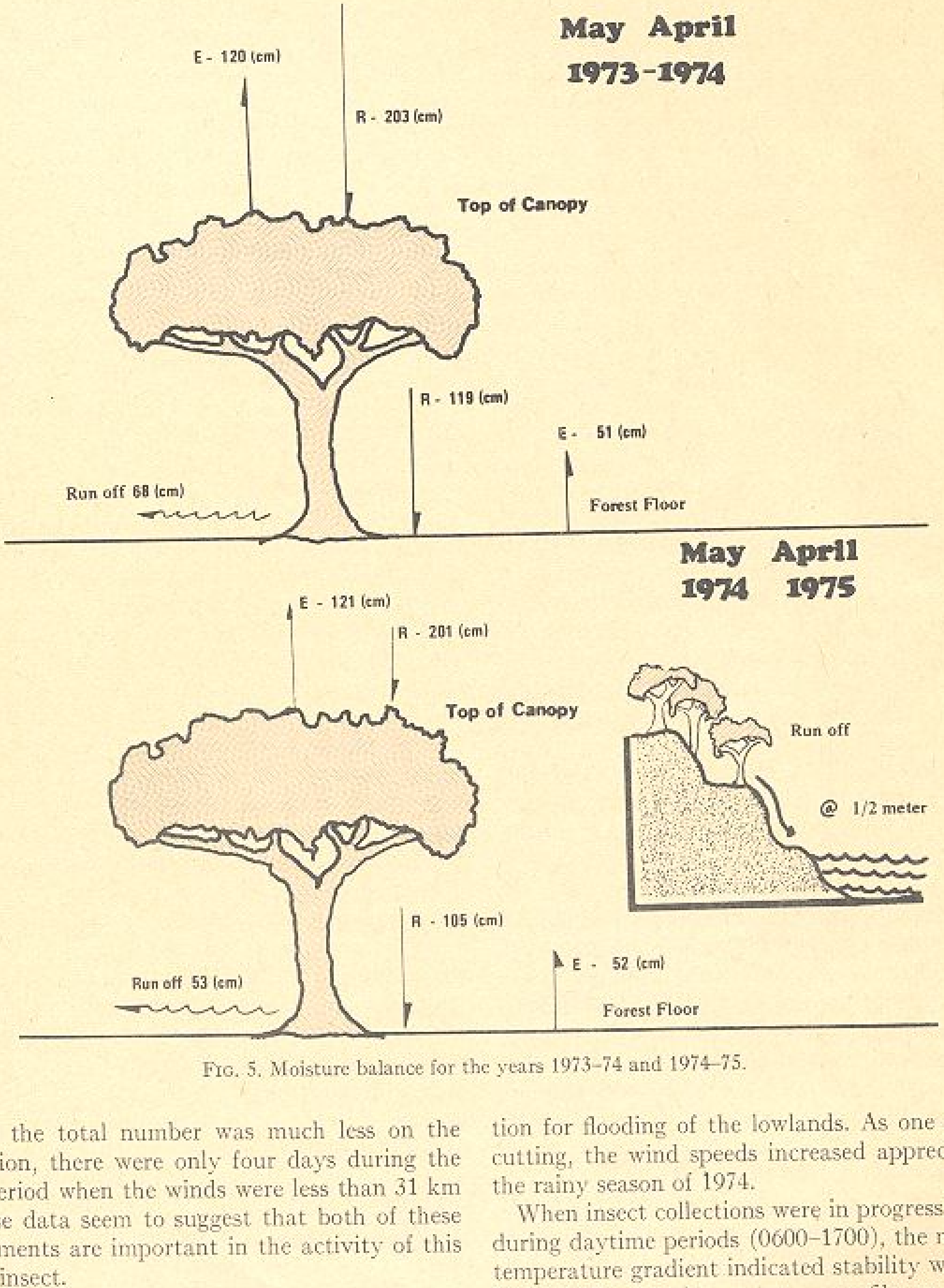

FIG. 5. Moisture balance for the years 1973–74 and 1974–75.

rain. While the total number was much less on the latter occasion, there were only four days during the collection period when the winds were less than 31 km day^{-1}. These data seem to suggest that both of these climatic elements are important in the activity of this man-biting insect.

As rainfall decreases and the net radiation increases with clear skies in the dry season, the wind speeds increase several times over those of the rainy season. Although heightened wind speeds and direction shifts occur preceding heavy rain, it appears that stronger wind speeds over a period of several days are an invariable signature for decreasing rainfall. During the rainy season, when rainfall does not occur for several days, the wind speed increases. After a period of no rain for several days, a slackening of the wind usually indicates that the rains will resume shortly. During the dry season of 1974, there was heavy cutting in the forested area surrounding the project site in preparation for flooding of the lowlands. As one result of the cutting, the wind speeds increased appreciably during the rainy season of 1974.

When insect collections were in progress in the forest during daytime periods (0600–1700), the mean vertical temperature gradient indicated stability with either an isothermal vertical temperature profile or a 1°C warmer canopy temperature. At night (1800–0500), the reverse was true and the vertical gradient of temperature indicated instability, with canopy temperatures 1–2°C cooler than at ground level. The ecological significance of the unstable nocturnal temperature gradient is found in the natural small updrafts and downdrafts associated with an unstable temperature structure, which permits easier vertical migrations of forest insects at night. During diurnal periods, the vertical motions of air might be expected to be dampened by isothermal or weak temperature inversions, thus hampering vertical migrations of insects.

5. Conclusions

When a project to build a large hydroelectric dam in the tropics is announced, it is only a matter of time before warnings are forthcoming on the possible consequences thereof. Often these are concerned with insect carriers of disease. Studies bearing on the ecology of an area to be flooded should be initiated at an early stage of dam development, so that forecasts based on data analyses can be taken into account to minimize health hazards and to prepare models for use in other projects. Such biological studies must be concerned with the physical factors of the microclimate and its changes, since these atmospheric variables are likely to control, to a large extent, the density fluctuations in the populations of insect disease carriers.

The changes in the ecological system, with impoundment, are expected to be drastic and readily identifiable. The changes in microclimate may be much more subtle. The preimpoundment microclimate in the forest at Los Altos de Maje appeared to be one of strong seasonality, with appreciable changes in the wind flow, sensible and latent heat flux, evaporation, rainfall and humidity. The water balance in a tropical forest is an important element which, to a large degree, determines the type of forest that develops as well as the composition of the microlimate within that forest. From an ecological as well as an engineering viewpoint, the evaporation-precipitation ratio and the amount of surface runoff from forested land are significant factors to be considered.

Acknowledgments. This research was supported under Grant AI-11889, awarded by the National Institutes of Health to the Gorgas Memorial Institute of Tropical Disease and Preventative Medicine. I would like to express appreciation to Rodolfo Hinds for invaluable assistance in the field and to laboratory technicians Orlando Ortiz, Belisario Polo and Nicki Angelos.

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